SPC overview: Beyond the Standard Model

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Overview

- One of the major efforts within USQCD is the study of models for **new physics Beyond the Standard Model (BSM)**.

- Of course, this is too generic: many things we study in heavy flavor, (g-2), nuclear structure are important inputs for new-physics searches.

- So, what I'm really reviewing as "lattice BSM" is "lattice calculations in strongly-coupled gauge theories other than QCD".

BSM and strongly-coupled gauge theory

- Strongly-coupled gauge theory can show up directly as a new BSM sector: **composite Higgs**, **composite dark matter**.

- Can also play a role in a larger sector, e.g. **supersymmetric** extensions of the SM required SUSY breaking, which can be gauge-induced.

- Most importantly, we learn new things about **strongly-coupled QFT** in general by studying examples that aren't QCD! Connections to other techniques: conformal bootstrap, AdS/CFT duality, …

- This is all exploratory, so *we don't need high precision!* (On the other hand, more degrees of freedom and slower RG running —> larger volume/discretization effects increases base cost vs. QCD.)

[1]V. Sanz and J. Setford, arXiv:1703.10190

Composite Higgs

- **Compositeness** is one solution to the hierarchy problem: no Planck-scale contributions to Higgs mass because confinement scale appears first. Experimentally, still need a “little hierarchy” from Higgs to other new (unobserved!) states.

- **Higgs as PNGB**: significant model-building activity. Light, SM-like Higgs by construction - parametric control over Higgs couplings with (v/f):

$$g_{H,SM} \to g_{H,SM}\left(1 + c\frac{v^2}{f^2} + \ldots\right)$$

v: Higgs vev
f: pion decay constant
c: algebraic constant

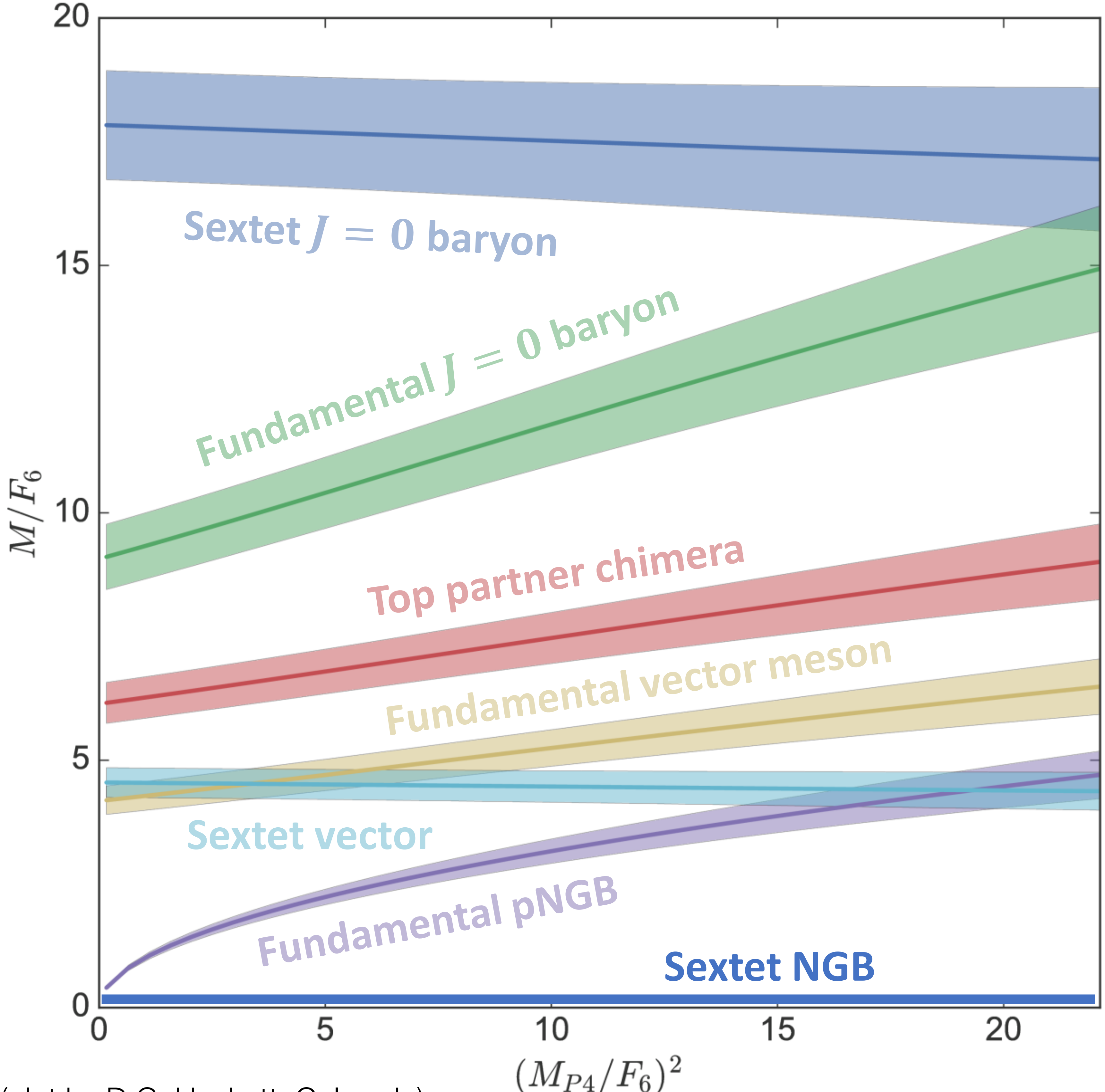
- Basic scenario is quite viable at LHC; f limit model-dependent but lower bound is 600 GeV[1], which means other resonances are easily multi-TeV scale.

- Lattice plays a role similar to QCD here: can study pheno with the low-energy chiral EFT, but lattice reduces many free parameters to a few fundamental inputs. Also reach beyond EFT to things like the overall spectrum.

(read **F_6~TeV** as a conservative estimate for plot units.)

<ins>Example</ins>: extrapolated lattice results for SU(4) with N_f=2 in both the F and AS_2 irreps.

Tel Aviv/Colorado collab, arXiv:1801.05809



QCD-colored composite states, including top partners (easy to see, but can be heavy!)

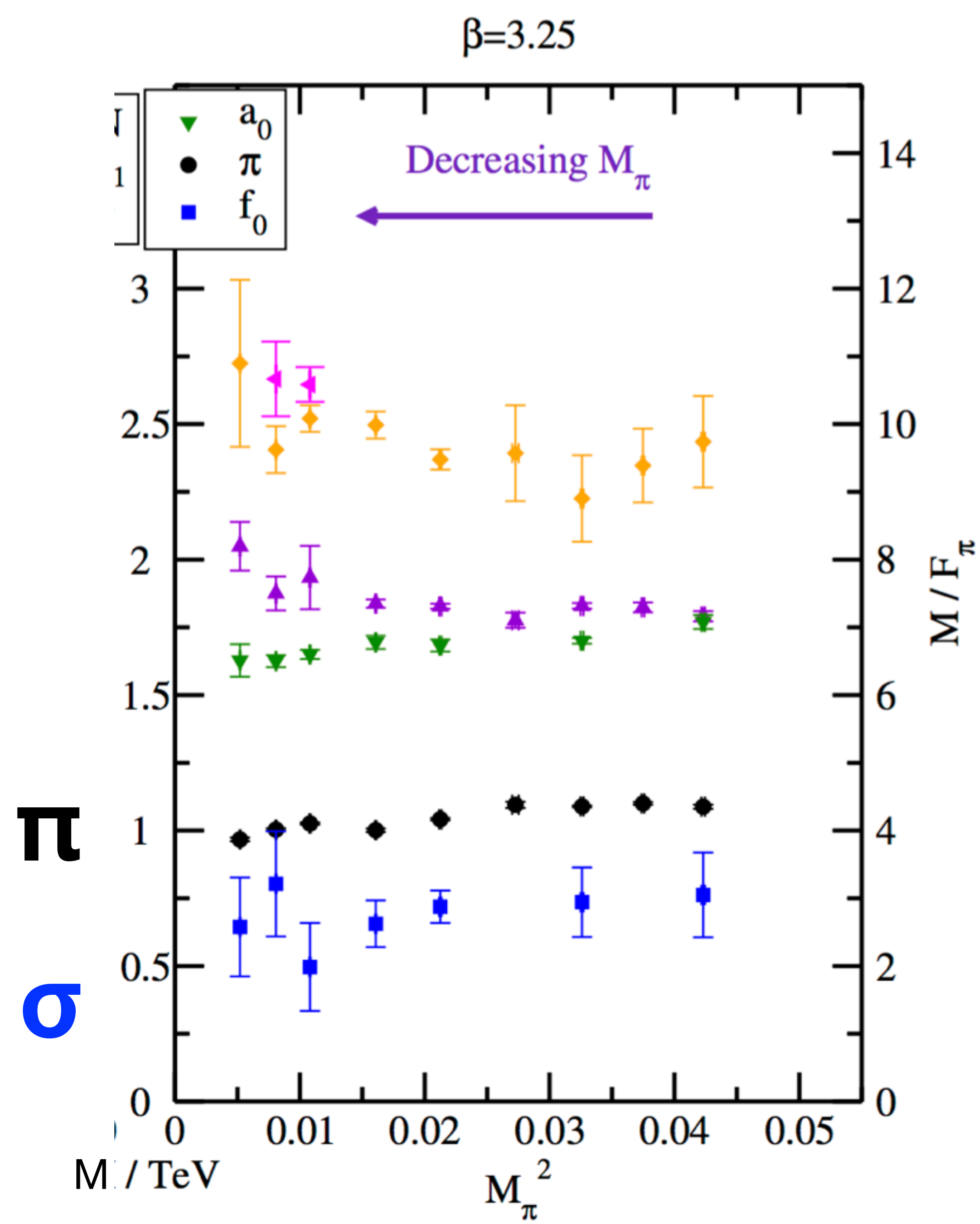
Higgs multiplet + other pure EW states (hard to see at LHC)

(plot by D.C. Hackett, Colorado)

Composite pseudo-dilaton Higgs?

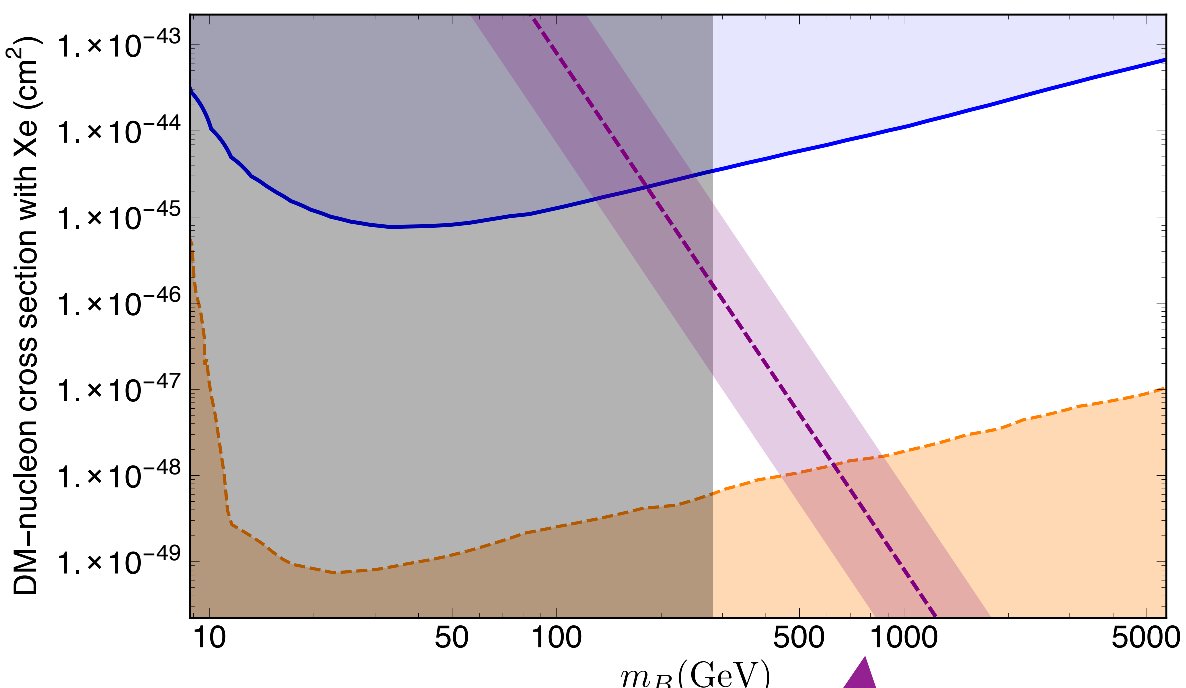
- Scalar “pseudo-dilaton” state - another dynamical option for Higgs to be much lighter than other new resonances?
- Lattice BSM groups have found multiple theories where 0++ scalar is unexpectedly light! (One example is SU(3) Nf=2 “sextet”, right.)
- Pheno is less clear here, partly because we don’t really know the right EFT if the pions aren’t alone! Lattice studies can help greatly here.

LatHC Collaboration, arXiv:1605.08750, PoS LATTICE2015, 310



Composite dark matter

LSD collab, PRL 115 (2015), 171803



DM cross-section through electromagnetic polarizability

- Dark matter has to be **neutral** and cosmically **stable**. In QCD, the neutron is neutral, and the proton is stable - so why not a new “dark QCD” where one “dark baryon” has both properties?

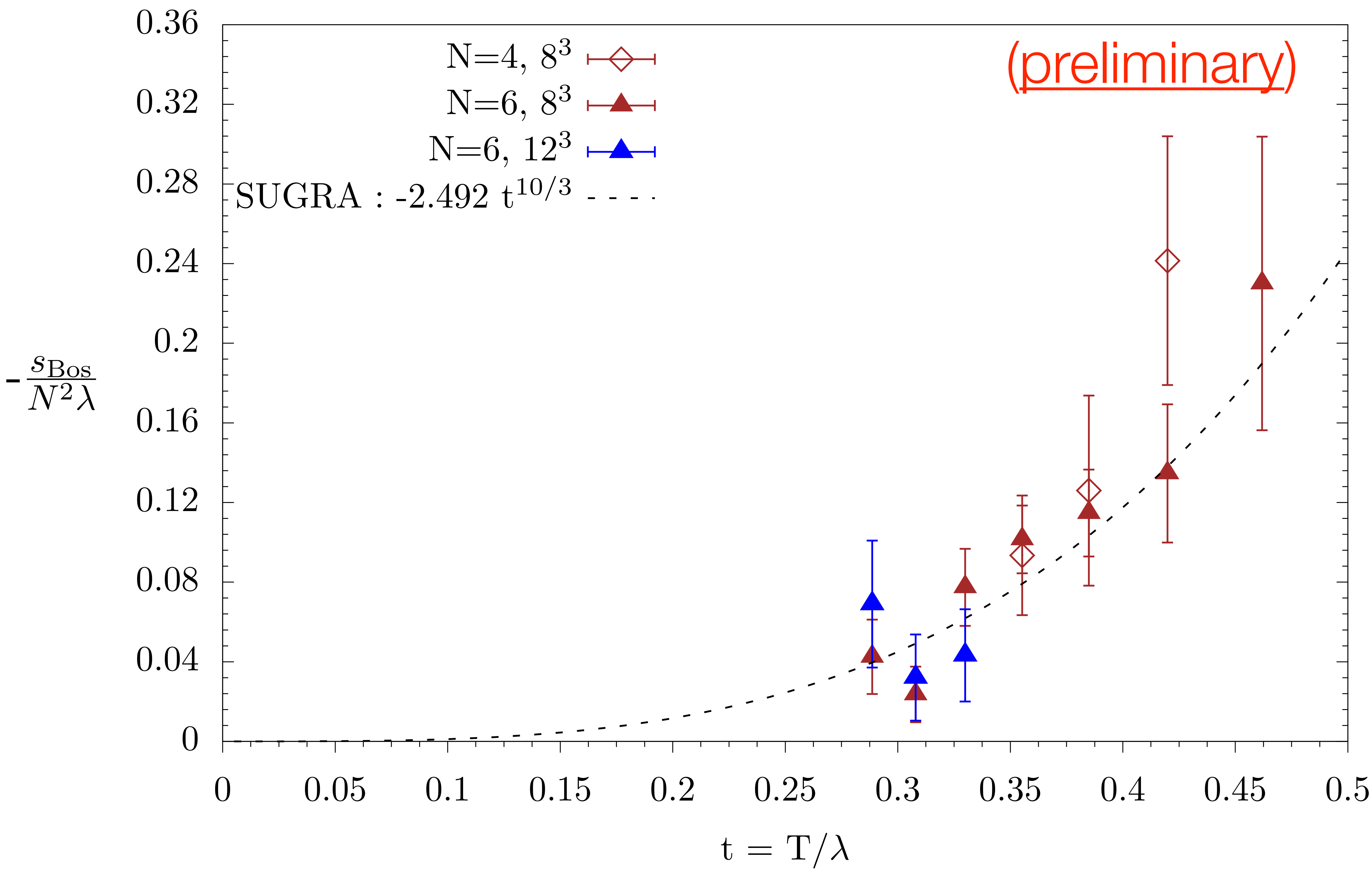
- Other options are viable, e.g. dark mesons and dark glueballs. Common thread is that DM candidate can have zero net charge, but constituents talk directly to SM (relic density!)

- Lots of **interesting questions for lattice**: form factors, “dark nuclear physics”, cosmic gravity waves, masses/ properties of other (charged!) states for collider searches.

Supersymmetry

- SUSY is generally hostile to lattice discretization due to close relation to space-time symmetries, but clever methods allow for a sub-symmetry to be preserved on the lattice
- N=4 SYM is one of the most-studied “toy models” due to AdS/CFT connection, but analytic methods work from the *weakly*-coupled sides. Lattice can work at strong coupling in the CFT directly, opening up non-perturbative tests of the duality.
- For more phenomenological things like MSSM, SUSY breaking is critical; lattice results have sighted dynamical breaking in lower-dimensional models, and further study is important.

Maximally supersymmetric super-Yang-Mills in d=3 (data) vs. supergravity dual prediction (dashed line)



(plot from Raghav Jha [Syracuse], from talk at Lattice for BSM Physics 2018)

http://www-hep.colorado.edu/~eneil/lbsm18/

- Ninth workshop in a series, connecting lattice BSM community to phenomenologists, experimentalists.
- Have a look for more details on what your lattice BSM colleagues are doing recently, and for some pheno perspectives!

Scientific Organizing Committee:

- Will Detmold (MIT)
- Masanori Hanada (Kyoto U.)
- Anna Hasenfratz (Colorado)
- Graham Kribs (Oregon)
- Adam Martin (Notre Dame)
- Ethan Neil (Colorado/RIKEN BNL)
- Pavlos Vranas (LLNL)
- Lian-Tao Wang (Chicago)

Local Organizing Committee:

- Venkitesh Ayyar (Colorado)
- Andrea Carosso (Colorado)
- Dan Hackett (Colorado)
- Anna Hasenfratz (Colorado)
- William Jay (Colorado)
- Ethan Neil (Colorado/RIKEN BNL)
- Pavlos Vranas (LLNL)
- Oliver Witzel (Colorado)

2018 class A proposals in BSM, by PI

- S. Catterall: “Thermodynamics of SYM theory in three and four dimensions.” **15.3M** Jpsi core-hr. [SUSY, strong QFT]

- J. Kuti: “Sextet BSM model of the near-conformal sigma-particle and its dilaton tests.” **29.1M** Jpsi core-hr. [Composite Higgs/pseudo-dilaton]

- C. Rebbi: “Step-scaling beta function for 10 fundamental flavors.” **21.5M** Jpsi core-hr. [strong QFT]

- O. Witzel: “Composite Higgs model with four light and six heavy flavors.” **34.3M** Jpsi core-hr. [Composite Higgs/PNGB]

BSM projects represent **5.1%** of the total resource request this year. Current efforts in all the areas I went through, except for dark matter.